Multi-Phase Sedment-Discharge Dynamics of Subglacial Drainage Recorded by a Glacier-Linked Esker in NW Tempe Terra, Mars

Conference or Workshop Item

MULTI-PHASE SEDIMENT-DISCHARGE DYNAMICS OF SUBGLACIAL DRAINAGE RECORDED BY A GLACIER-LINKED ESKER IN NW TEMPE TERRA, MARS.

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Introduction: Our recent discoveries of eskers associated with 110–150 Myr old debris-covered glaciers in Phlegra Montes [1] and NW Tempe Terra [2], Mars, indicate that localised wet-based glaciation has occurred in at least two locations during the late Amazonian, despite cold climate conditions. Eskers are sedimentary ridges deposited by meltwater flowing through drainage tunnels within or beneath glaciers. In this study, we use new 3D measurements of the NW Tempe Terra esker (46.17 °N, 83.06 °W) to develop a conceptual model for the sediment-discharge dynamics of the esker-forming drainage episode(s).

Methods: Following [3], we used a 2 m/pixel digital elevation model derived from High Resolution Imaging Science Experiment (HiRISE) images to measure ridge height (H) and width (W) every ~20 m along the esker. We exclude ridge portions obscured by the parent glacier (Fig 1), as well as transitions between morphological zones.

Results: A scatterplot of the raw height and width measurements (Fig 2A) has multiple limbs which correspond to subzones of the esker with common morphological characteristics (Fig 1).

Subzones IIa and IIIc both have, wide, broad-crested morphologies, and follow similar height-width (H-W) trends (Fig 2A). Northward of subzone IIIc (in zone IV), the ridge transitions to narrower, sharp-crested morphology (Fig 1A), which exhibits a steeper H-W trend (Fig 2A) and has distinctly lower widths and typical heights than subzones IIa and IIIc.

Subzones IIb, IIIa, and IIIb, have a similar range of widths to subzones IIa and IIIc, but are taller. In these subzones the ridge has wide, broad lower flanks, and a narrower, relatively steep-sided central prominence (Fig 1B). In subzones IIb and IIIa, the central prominence is sharp- to multi-crested. In subzone IIIb, it is fan-shaped, and grades into the surface of the broad-crested portion of the ridge in subzone IIIc. There is no evidence of a central prominence northward of the subzone IIIb–c transition (Fig 1B).

These observations lead us to propose that subzones IIb–IIIb of the NW Tempe Terra esker comprise 'stacked' esker ridges, i.e., that a narrow sharp- to multi-crested 'upper member' (Umb) ridge was deposited atop an underlying broad-crested 'lower member' (Lmb) ridge. This morphology could have formed as

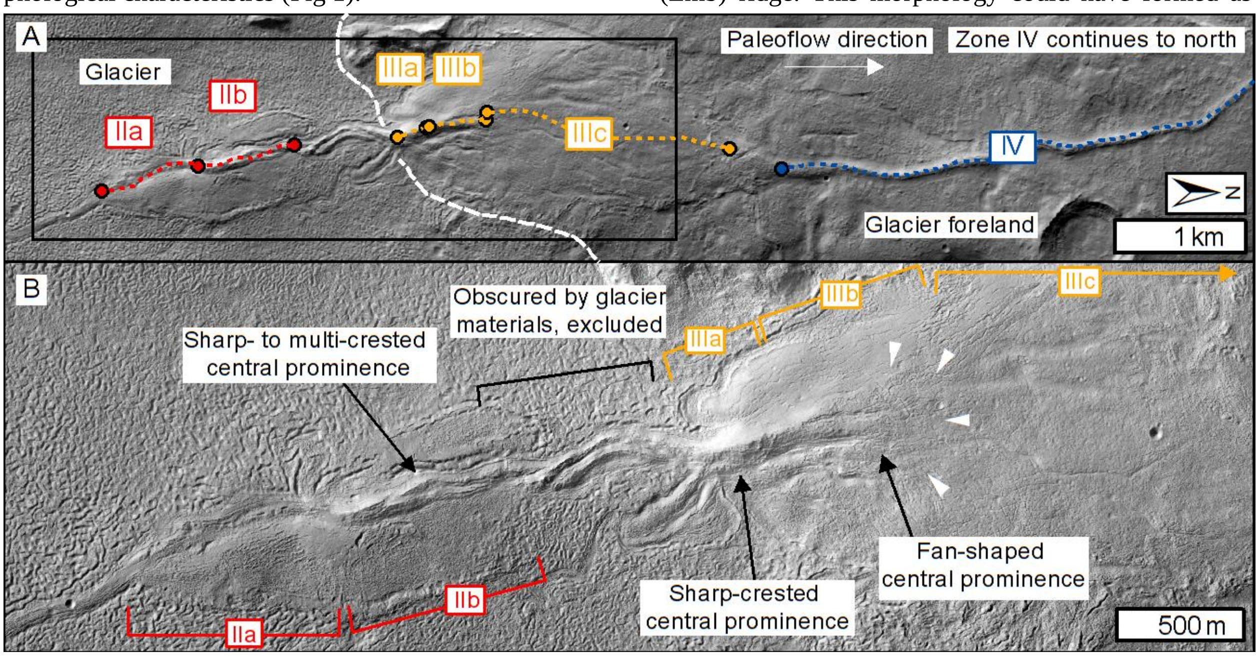

Figure 1: ***(A)*** *Context Camera image of the NW Tempe Terra esker showing morphological zones (II–IV) and subzones (letters). Dotted lines show sampled ridge portions. White dashed line is present glacier terminus.* ***(B)*** *The stacked portion of the esker in subzones IIb–IIIb (HiRISE image; extent in A).White arrows indicate the terminus of the central prominence.*

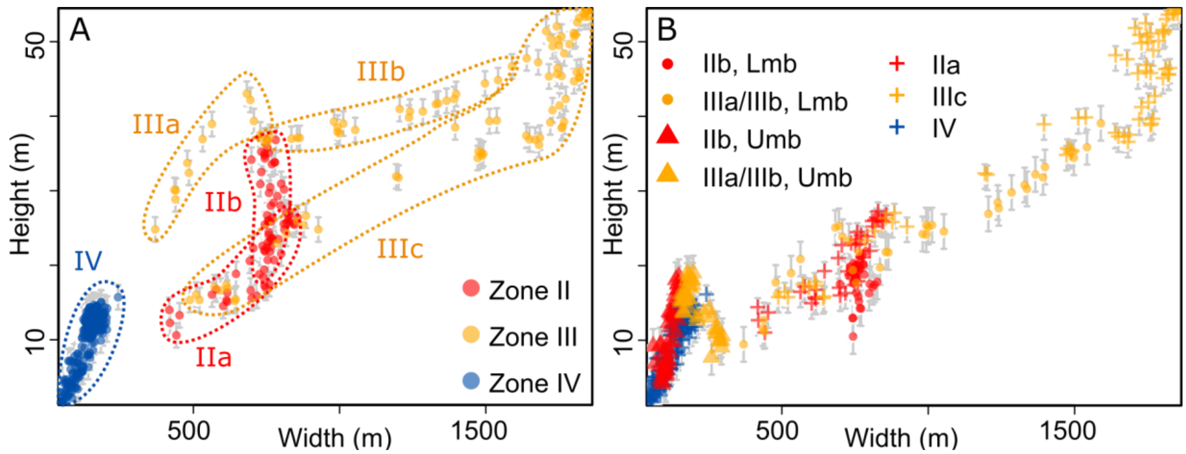

Figure 2: ***(A)*** *Raw H and W measurements for the NW Tempe Terra esker. Dotted lines delineate limbs corresponding to morphological subzones (see Fig 1).* ***(B)*** *H and W measurements with the upper and lower ridge members (Umb and Lmb, respectively) in subzones IIb and IIIa–b separated.*

the parent meltwater conduit shrank under waning sediment supply and/or flow power [4].

Analysis: To explore this hypothesis, we measured the height and width of the Umb in subzones IIb–IIIb, at the same sample locations as for the raw measurements. We subtracted the height of Umb from the raw height measurements to give the height of the Lmb.

We then predicted the H-W relationships for the Umb and Lmb in subzones IIb–IIIb based on those observed for morphologically similar ridge portions where there is no evidence for esker stacking. We predicted that: (1) the H-W relationship of the sharp- to multi-crested Umb in subzones IIb–IIIa would follow a similar trend to the sharp-crested zone IV ridge; (2) the H-W relationship for the broad Lmb would follow a similar trend to the broad-crested portions of the ridge in subzones IIa and IIIc; and (3), the H-W relationship for the fan-shaped terminus of Umb in subzone IIIb would follow a transitional trend between the sharp- to multi-crested sections and the broad-crested sections.

Fig 2B shows that the above predictions correspond remarkably well with the observed heights and widths of the Umb and Lmb ridges, supporting our 'stacked esker' hypothesis.

Discussion and Conclusions: Based upon morpho-sedimentary relationships observed along eskers on Earth (e.g., [4]), we propose that the stacked morphology of the NW Tempe Terra esker represents changes in sediment supply and/or flow power of meltwater drainage. A possible two-phase model for its formation is as follows.

Phase 1: Initial, high-power flows were heavily sediment-laden. Rapid deposition on the conduit floor in zones II–III created conduit blockages. Resulting increases in hydraulic pressure initiated a positive feedback cycle in which conduit growth and migration around the blockages formed cavities that encouraged further sedimentation and conduit migration around growing sedimentary depocentres. These depocentres formed the broad-crested portions of the Lmb in zones II–III. Depocentre growth reduced sediment supply to zone IV, preventing similar large-scale conduit blockages down-flow. Thus, the zone IV conduit did not undergo significant vertical or lateral migration, and formed a relatively narrow, sharp-crested ridge.

Phase 2: Meltwater flow power and/or sediment supply waned towards the end of the esker-forming drainage episode(s). The ice-confined meltwater conduit shrank to compensate for the resulting reduction in hydraulic pressure. Reduced sedimentation rates precluded the requirement for conduit migration, forming the narrow, sharp- to multi-crested Umb atop the broad-crested Lmb in subzones IIb–IIIb. Northward of subzone IIIb, the conduit retained its Phase 1 geometry beneath thinner ice. Meltwater entering subzone IIIb dispersed over the broad-crested Lmb surface, forming the fan-shaped Umb in this subzone, and explaining the absence of a central prominence beyond the fan.

Conclusions: We used a novel morphometric approach to reconstruct the multi-phase sediment-discharge dynamics of esker formation in NW Tempe Terra, Mars. Such reconstructions provide essential insights for our ongoing glacial flow modelling, which aims to reconstruct the environmental drivers of recent wet-based glaciation on Mars.

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